Optimum stand density of Chinese pine forests in Taihang limestone mountains, Shanxi Province

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Abstract Data analysis was made for 54 stands of Chinese pine forests for soil and water conservation and timber. The regression equations were drawn up on forest density and different rafter timber and bush coverage. Based on those equations, the number of rafter timber trees, storage, number of non-rafter timber trees, stand volume and the output value were calculated for six different forest densities ranged from 1 250 to 6600 trees/hm^2. According to the economic and ecological criteria, the optimum density for Chinese pine forests was determined as 1 650 trees/hm^2.

Key words: Taihang Mountains, Limestone mountains, Chinese pine, Water and soil conservation, Timber forest, Forest density

Introduction

Chinese pine (*Pinus tablaeformis)* is one of the most important tree species for afforestation and widely spread in Taihang limestone mountains, Shanxi Province. It takes 85% of the total area of plantations. Chines pine plantations planted are mainly for purpose of soil and water conservation and timber. The investigation of Chinese pine plantations made last decade showed that, according to their site condition, the existing stands did not meet the appropriate density. Stands structure is uniform. Water loss and soil erosion are serious, and soil fertility get declining. Our research focuses on the optimum stand density for both purposes of soil and water conservation and timber forest.

The investigation of Chinese pine plantations was carried out in Pingshun, Lucheng, Huguan, Jincheng and Wuxiang counties in southeast of Shanxi Province. The closure of stands is 0.5~1.0, age 25~35a, altitude 800~1 800 m, soil depth 16~30 cm, area 300~667 m^2, and the density is 1 200~7 500 trees/hm^2.

Methods

The purposive sample plots and investigation of the bush and grass coverage were arranged according to the types of soil and water conservation and timber forests, combined with site altitude, slope direction and soil depth.

The DBH and height of different rafter timber are calculated using the analysis data of 23 standard trees (see Table 2)

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Table 2. DBH and tree height of Chinese pine raft timber

Timber length /m	Diameter of smaller end /cm	DBH /cm	DBH over bark /cm	Tree-height /m
2	4	5.9	6.3	4.1
2	6	7.2	7.7	4.8
3	6	9.3	9.9	4.9

The DBH was recorded in 2-cm diameter scales. The inserting method was used to calculate the real tree number in the diameter scale, tree number per hectare, average DBH and under-standard tree number.

We used single entry volume table of Chinese pine plantation of Shanxi Province (Shanxi Standard Bureau 1985), according to the average diameter at breast-height, to calculate the stand volume and the storage per hectare.

Results and analysis

Establishment of regression equation

The regression equations of stand density and tree number of raft timber are set up by using the data of 44 purposive sample plots, 3 rafter tree criteria and IBM-PC series program (Lang *et al* 1989)

After inspection, the optimum regression equations for 3 rafter tree types are:

(i) Length: 2 m, top diameter: 4 cm.

$$Y_{(2\text{m},4\text{m})} = -235.2243 + 0.3135X \quad (1)$$

Where: Y is tree number of rafter timber,
X is stand density.

Density range is 1 300~7 500 trees/hm^2, and correlation coefficient is R=0.9422 $>r_{0.01}$ =0.4487. This

indicates that the equation is significantly correlated.

(ii)Length: 2 m, top diameter: 6 cm

$$Y_{(2m,6cm)} = -269.0450+0.04081X-0.0000045X^2 \quad (2)$$

$R=0.8986 > r_{0.01} = 0.4871$

(iii) Length: 3 m, top diameter: 6 cm

$$Y_{(3m,6cm)} = -281.7453+0.7088X-0.0002X^2 \quad (3)$$

$R=0.9253 > r_{0.01} = 0.5366$

Density scale: 1300~4000 tree/hm^2

Relationship of stand density volume and tree number of rafter timber

When the density is 1 250~6 600 trees/hm^2, the tree number of different grade rafter timber and non-rafter tree number can be calculated from the regression equations. In 6 kinds of stand densities, from 1 250 to 6 600 trees/hm^2, the stand with the density of 2 500 trees/hm^2 has the biggest rafter timber volume (40.3 m^3/hm^2), following by the stand with densities of 1 650 trees/hm^2, 1 250 trees/hm^2 and 3 300 trees/hm^2 (Table 2).

Table 2. Rafter tree number and volume with different stand densities

Density /trees • hm^{-2}	Rafter timber									Rafter timber volume	Non-rafter Trees	
	2-m length and 4-cm top diameter			2-m length and 6-cm top diameter			3-m in length and 6-cm top diameter					
	Number	%	Volume / m^3	Number	%	Volume / m^3	Number	%	volume / m^3		Number	%
1250	156	12.5	1.919	209	16.7	4.368	855	68.4	27.788	34.075	30	2.4
1650	282	17.1	3.299	349	21.2	6.736	907	55.0	27.880	37.880	112	6.8
2500	549	22.0	5.984	626	25.0	11.080	804	32.2	23.236	40.300	521	20.8
3300	799	24.2	8.070	859	26.0	14.002	442	13.4	11.890	33.962	1200	36.4
5000	1332	26.6	11.722	1271	25.4	18.430	--	--	--	30.152	2397	47.9
6660	1834	27.5	14.855	1062	15.9	14.443	--	--	--	29.298	3764	56.5

For 3-m length & 6-cm top diameter rafter timber, the stands with the densities of 1 250 trees/hm^2 and 1 650 trees/hm^2 have the biggest volumes, 27.788 m^3/hm^2 and 27.845 m^3/hm^2 respectively, and the volume gets obviously declining with the increasing of stand density. The volumes of 2 m & 4 cm rafter timber and 2 m & 6 cm rafter timber show an increasing trend when the densities of stand get increase.

Meanwhile, there is a close relationship between non-rafter tree number and stand density. For the stand with density of 1 250 trees/hm^2, non-rafter trees accounts for 2.4%. While the stand density is 1 650 trees/hm^2, non-rafter trees accounts for 6.8%. The non-rafter tree number increases with increase of stand density. The non-rafter trees take more than 50% in the stand with the density of 6 660 tree/hm^2, and the differentiation of tree is serious.

Economic value of rafter timber

Rafter tree number with different value varies with stand density. To analyses the economic value of different density stands, we calculated the timber value according to present market price. Table 2 shows the volume of rafter timber, which is tree storage. Given 70% as production rate. The rafter value under different densities is shown in Table 3.

Table 3. Rafter value in different stand densities (Unit: 10 000 yuan/hm^2)

Rafter timber	Stand density /trees • hm^{-2}						Note
	1250	1650	2500	3300	5000	6600	
2m, 4cm rafter	0.03	0.05	0.09	0.12	0.18	0.23	220 yuan/m^3 for 2m,4cm 276 yuan/m^3 for 2m,6cm 332 yuan/m^3 for 3m,6cm
2m, 6cm rafter	0.08	0.13	0.21	0.27	0.43	0.28	
3m, 6cm rafter	0.65	0.65	0.54	0.28	-	-	
Sum	0.76	0.83	0.84	0.67	0.61	0.51	

From Table 3 it can be found that in the stands with 2 500 and 1 650 trees/hm^2 densities, rafter timber get the highest economic values, 8 400 yuan/hm^2 and 8 300 yuan/hm^2 respectively. The former is 850 trees more than that of the latter. For the 3 m & 6 cm rafter they are almost the same in value per unit area.

Density and bush coverage

Using 34 purposive sample plots data, the regression equation of stand density and bush coverage is.

$$Y=0.5515\times0.9996^X \quad (4)$$

In equation (4), Y is bush coverage (%); X is the density (trees/hm^2), correlation coefficient R=0.9258, $|R|>R_{0.01}$=0.4487. Using equation (4), the bush coverage in different densities stands (Table 4) was calculated. When density increases, the bush coverage

decreases.

Table 4. Bush coverage in stands of different densities

Stand density /trees • hm^{-2}	Bush coverage /%
1250	33
1650	28
2500	19
3300	14
5000	7
6600	4

Soil and water conservation function of different density stands

Table 5 and 6 show that the stand composed by Chinese pine and bush is better than pure Chinese pine stand in soil and water conservation. When the stand density decrease, the litter's water absorption increase and soil erosion decrease. When pine density is 2 500, 1 650 and 1 250 trees/hm^2, the water holding capacity of litter is 1.02, 1.10 and 1.12 times that of pure pine stand, and water absorption is 1.12 and 1.40 and 1.53 times that of pure pine forest, and soil erosion is reduced by 25%, 10% and 9.7%.

Table 5. Litter water absorption in different density stands

Tree	Age	Density /trees • hm^{-2}	Bush Coverage /%	Litter Thickness /cm	Dry Weight /t • hm^{-2}	Water Holding /mm	Water absorption Rate /%	Absorption /t • hm^{-2}
Pure pine	35	5000	5	3.0	23.18	4.1	179.6	41.48
Pine+bush	32	2500	10	4.0	25.2	4.6	183.2	46.16
Pine+bush	32	1650	30	4.5	29.4	5.8	198.1	58.24
Pine+bush	35	1250	35	4.2	31.7	6.4	200.7	63.62

Table 6. Soil erosion in different density stands

Tree	Age /a	Density /trees • hm^{-2}	Bush Coverage /%	Rainfall /mm	Average rain Intensity /mm • min^{-1}	Erosion /t • hm^{-2}
Pure pine	35	5000	5	74	1.08	6.60×10^{-4}
Pine+bush	32	2500	15	74	1.08	1.62×10^{-4}
Pine+bush	32	1650	30	74	1.08	6.58×10^{-5}
Pine+bush	35	1250	35	74	1.08	6.42×10^{-5}

Notes: using artificial rain fall

Conclusion

In 6 kinds of stand densities, from 1 250 to 6 660 trees/hm^2, the stand with density of 2 500 trees/hm^2 has the biggest rafter storage and highest economic value, following by the stand with density of 1 650 tree/hm^2. Their storage difference is 6.0% and value difference is 1.2%, no big difference. But comparing to the composition and the proportion of non-rafter, the stand density of 1 650 trees/hm^2 is better than the density of 2 500 trees/hm^2. In the stand of 1 650 trees/hm^2 density, the rafter storage of 3 m in length and 6 cm in top diameter accounts for 73.5%, 2 m & 4 cm rafter accounts for 8.7% and non-rafter takes up 6.8%. In the stand of 2 500 trees/hm^2 density, the above proportion is 57.7%, 14.8%, and 20.8%, forest tree number increases 51.5%, and the afforestation cost is also increased.

According to the report by Jia Shaofeng, when the forest's closing degree or vegetation total coverage reaches 40%, its water and soil conservation function will get great changing, and compared with exposed land, 50% of soil erosion could be reduced. When the total vegetation coverage reach 80%, there is no erosion. From Table 4, we know that bush coverage of 1 650 trees/hm^2 density can reach to 30%. Summing up from table 2 to 6, appropriate density is about 1 650 trees/hm^2, where we get both economic value and ecological benefit.

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